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# Radiation physics constraints on global warming

*By Denis G. Rancourt*

**Abstract** – I describe the basic physics of planetary radiation balance and surface temperature, in the simplest and most robust terms possible that capture the essential ingredients of planetary greenhouse warming. I show that the often repeated textbook and scientific report view that the Earth's surface temperature would be  $-19^{\circ}\text{C}$  in the absence of a planetary greenhouse effect (a  $33^{\circ}\text{C}$  greenhouse effect difference) is wrong; and that an accepted calculation of the "longwave radiative forcing" by atmospheric greenhouse gases is also wrong. Our simple radiation-balance model – using only (i) the satellite-measured absolute longwave Earth emission, (ii) a present mean global surface temperature of  $14^{\circ}\text{C}$ , (iii) the satellite-measured fraction of longwave absorbance due to  $\text{CO}_2$ , (iv) a satellite-measured global mean surface albedo of 0.30, (v) the season-average solar constant and (vi) Kirchoff's Law – predicts: (a) a total longwave emission atmospheric mean transmittance of  $\langle\tau_{\text{e}}\rangle = 0.89$ , (b) a zero-greenhouse-effect Earth mean surface temperature of  $T_0 = 5.5^{\circ}\text{C}$ , (c) a global mean surface emission intensity of  $269 \text{ W/m}^2$ , (d) a post-industrial warming due only to  $\text{CO}_2$  increase of  $\Delta T_{\text{ind}} = 0.56^{\circ}\text{C}$ , (e) a temperature increase from doubling the present  $\text{CO}_2$  concentration alone (without water vapour feedback) equal to  $\Delta T_{\text{dbl}} = 2.0^{\circ}\text{C}$ . Earth's radiative balance determining its surface temperature is shown to be one order of magnitude more sensitive to solar irradiance and to planetary albedo/emissivity than to all atmospheric greenhouse effects combined. All the model predictions robustly follow from the starting assumptions without any need for elaborate global circulation models. A recent critique of the dominant climate change science narrative is evaluated in the light of our model.

## Simplest model with essential features

The concepts of radiation physics are easy to explain but difficult to understand. Here we show that even the most fundamental concepts of albedo and emissivity have not been completely appreciated by most seasoned scientific writers addressing the phenomenon of a planetary greenhouse effect.

Let us start by building the simplest possible model of planetary radiation balance, realistic enough to capture the essential global average features.

We take the planet to be a perfect sphere with a smooth and homogeneous surface and to have a thin (compared to the planet radius) and homogeneous atmosphere. The planet is uniformly irradiated by a distant sun.

The incident intensity (in Watts per square-meter,  $\text{W/m}^2$ ) of “shortwave” radiation (largely visible light) from the sun at the planet is the so-called solar constant,  $I_s$ , where for Earth  $I_s = 1366 \text{ W/m}^2$  (having a real seasonal variation in magnitude from 1412 to  $1321 \text{ W/m}^2$ , or 6.7% of its average value).

Different parts of the planet’s surface receive different intensities of incident shortwave radiation. This is because the surfaces at different latitudes receive the incident rays at different angles and because half of the planet’s surface is shielded from all incident rays (only one hemisphere is exposed to the sun at any given time).

Rather than deal with the latter complexity of non-uniform irradiation, instead we take the entire planet’s surface to be uniformly irradiated with an intensity equal to the corresponding average solar constant. The correct average solar constant is  $\langle I_s \rangle = (1/4)I_s = 341.5 \text{ W/m}^2$ , as is well known and easy to calculate.

In our model, therefore, every part of the planet’s surface is identical in terms of the radiation balance conditions. Each part of the planet’s surface represents what is happening on average, in terms of radiation balance, and of the planet properties which we will take to be the Earth’s average properties.

Of all the incident shortwave solar radiation that strikes the planet a fraction is reflected back into outer space without being absorbed by any part of the planet (surface or atmosphere). This fraction (from zero to one) of the incident shortwave solar radiation energy that is reflected out from the planet is called the planet’s albedo. Put simply:  $\text{Albedo} = \text{Solar-Out}/\text{Solar-In}$ .

The reflected outgoing shortwave radiation need not have the same spectral distribution (radiation intensity versus radiation frequency or wavelength) as the incoming incident solar shortwave radiation because the amount of absorption/reflection can be (and generally is) dependent on wavelength. The albedo is the net energy fraction that is reflected.

Modern satellite spectroscopic measurements can quantify the solar constant and the amount of out-reflected shortwave radiation, can resolve these radiations from longwave thermal radiation, and can measure continuously in orbit to obtain planet-wide averages.

Satellite measurements allow us to conclude that the average Earth albedo is  $\langle a \rangle = 0.30$  [1]. Arguably-more-direct and reliable Earth-based so-called “Earthshine observation” measurements give  $\langle a \rangle = 0.297(5)$  where, using scientific error notation, the latter means

$0.297 \pm 0.005$  [2]. There are daily changes in Earth's albedo (from large scale weather changes) of ~5% and seasonal variations of ~15% (from snow and ice cover, vegetation, and weather and cloud cover) [2].

The source of heat on the planet is taken to be the planet's surface that absorbs shortwave solar radiation. The physical absorption process transforms the electromagnetic energy of the incident solar radiation into heat energy (vibrational energy of the surface's molecules).

Any opaque body at any temperature above 0 K (i.e., having vibrating rather than motionless molecules) in turn emits electromagnetic radiation. The latter so-called "thermal" or "black-body" radiation has characteristics that depend of the body's (emitting) surface temperature. For the temperatures of interest the surface thermal radiation is shortwave (or infra-red) radiation.

The intensity  $I_e$  (in W/m<sup>2</sup>) of the emitted thermal (shortwave) electromagnetic radiation coming from the surface of an opaque body is given by the Stefan–Boltzmann law:

$$I_e = \epsilon \sigma T^4 \quad (\text{eq.1})$$

where  $T$  is the temperature of the emitting surface in K,  $\sigma$  is the Stefan–Boltzmann constant  $\sigma = 5.6704 \times 10^{-8} \text{ W/m}^2\text{K}^4$ , and  $\epsilon$  is the "emissivity" of the emitting surface. "10<sup>-8</sup>" means times 10 to the power minus-eight, giving  $0.000000056704 \text{ W/m}^2\text{K}^4$ .

The emissivity has a dimensionless value between zero and one. It is the fractional energy emission from the surface compared to the surface's emission if it were an ideal black body emitter.  $\epsilon = 1$  for an ideal black body surface and  $\epsilon = 0$  for an ideally reflective surface (i.e., a surface having an albedo of exactly 1).

The global average emissivity,  $\langle \epsilon \rangle$ , of Earth's surface is virtually impossible to measure. It can at best be reasonably estimated or deduced from relevant physical principles. This is a central difficulty in calculating Earth's radiative behaviour.

Before we address the latter difficulty regarding  $\langle \epsilon \rangle$ , let us next describe how the planet's mean surface temperature is established.

If the net radiant energy into the planet is larger than the net radiant energy escaping from the planet then the net received energy will heat the planet and increase its temperature. Likewise, if the net radiant energy out from the planet is larger than the net energy into the planet then the net loss of energy of the planet will cause the planet to lose heat and decrease its temperature.

Therefore, in a "steady state" situation, after a certain planetary response time following any change affecting radiation balance, the temperature of the planet's surface will stabilize at some value corresponding to the rate of energy-in being equal to the rate of energy-out and there will be "radiation balance" at a stable surface temperature.

The net energy-in is the incident solar radiation minus the albedo loss. The net energy-out is the portion of all the shortwave emission energy that manages to escape the planet into outer space. By setting in = out we can solve for the resulting radiation-balancing planet surface temperature.

The corresponding radiation balance equation, therefore, is:

$$\langle I_s \rangle (1 - \langle a \rangle) = \langle t_e \rangle \langle \epsilon \rangle \sigma T^4 \quad (\text{eq.2})$$

where  $\langle t_e \rangle$  is the fractional transmittance (having a dimensionless value between zero and one) of the total emitted shortwave radiation energy.

In other words,  $\langle t_e \rangle$  is the planetary average transmission coefficient for escape of the emitted shortwave radiation through the atmosphere and into outer space. In the absence of all greenhouse effects  $\langle t_e \rangle = 1$ . For a completely infrared-opaque atmosphere  $\langle t_e \rangle = 0$ .

Solving for the planet surface temperature (in K), eq.2 gives:

$$T = [ (1 - \langle a \rangle) \langle I_s \rangle / \langle t_e \rangle \langle \epsilon \rangle \sigma ]^{(1/4)} . \quad (\text{eq.3})$$

Eq.3 is the central result for the steady state surface temperature in our simplest possible radiation balance model.

### **Evaluating needed parameter $\langle t_e \rangle \langle \epsilon \rangle$**

Note that  $\langle t_e \rangle$ , like  $\langle \epsilon \rangle$ , is virtually impossible to measure. It is usually only (incorrectly, see below) estimated using model assumptions (e.g., [1]: Fig.1). Note also, that for infrared-opaque atmospheres, as  $\langle t_e \rangle$  approaches a value of zero the resulting temperature tends to an infinite value (things get very hot).

On the other hand, the average net outgoing shortwave intensity,  $\langle t_e \rangle \langle I_e \rangle$ , is accurately measured by satellite [1]. It is  $\langle t_e \rangle \langle I_e \rangle = 238.5 \text{ W/m}^2$  [1]. Since the global average surface temperature is accepted to be accurately known [3], it is therefore possible to calculate the value of the product quantity  $\langle t_e \rangle \langle \epsilon \rangle$  for Earth as:

$$\langle t_e \rangle \langle \epsilon \rangle = \langle t_e \rangle \langle I_e \rangle / \sigma T^4 \quad (\text{eq.4})$$

by using  $T = 287.15 \text{ K}$ , since the reported mean surface temperature is  $14.0^\circ\text{C}$  [3].

This, to our knowledge, gives the first accurate evaluation of  $\langle t_e \rangle \langle \epsilon \rangle$  for the current Earth as  $\langle t_e \rangle \langle \epsilon \rangle = 0.62$ .

[Note that all such products of average physical parameters assume statistical independence of the parameters, or that the inter-parameter correlations do not affect the averaging – that is, we assume  $\langle \epsilon \rangle = \langle \epsilon \rangle$  and so on.]

As a self-consistency verification, using the latter value of  $\langle \epsilon \rangle$  in eq.3 indeed gives a mean surface temperature of 14.0 °C, as expected since satellite measurements confirm the near equality  $(1 - \langle a \rangle) \langle I_s \rangle = \langle \epsilon \rangle \langle I_e \rangle$  relating energy-in and energy-out [1].

Having determined the Earth value of  $\langle \epsilon \rangle$ , one might be tempted to use the determined value in eq.3 and explore the impact of variations in  $\langle a \rangle$ . This would be a grave error however because  $\langle \epsilon \rangle$  and  $\langle a \rangle$  are highly anti-correlated parameters. For all Earth surface materials, a low value of albedo corresponds to a high value of  $\epsilon$  and vice versa (Kirchoff's Law).

## Earth temperature with zero greenhouse effect, $T_0$

Next, we calculate the Earth's mean surface temperature in the absence of all greenhouse effects, when  $\langle \epsilon \rangle = 1$ . We take " $T_0$ " to be the symbol for the latter zero-greenhouse-effect surface temperature. In order to use eq.3 for this purpose it is necessary to know the Earth value of  $\langle \epsilon \rangle$  itself.

Possibly because  $\langle \epsilon \rangle$  cannot be measured and is not known, virtually all researchers and authors have incorrectly used  $\langle \epsilon \rangle = 1$ . That is, they have assumed that the Earth's surface is an ideal black body emitter.

Using the latter assumption for  $\langle \epsilon \rangle$  and with  $\langle \epsilon \rangle = 1$  eq.3 gives  $T_0 = 254.8$  K or minus (–) 18.3 °C. Compared to the accepted actual mean global surface temperature of 14.0 °C this would imply a total global greenhouse effect warming on Earth of 32.3 °C – corresponding to the repeatedly stated textbook value of 33 °C of greenhouse effect warming [4]. I also taught this value in my university physics courses and repeated it in my 2007 critique of global warming [5]. Wikipedia is no exceptions [6]. American Geophysical Union (AGU) press releases typically announce [7]:

*“Overall, the greenhouse effect warms the planet by about 33 °C, turning it from a frigid ice-covered ball with a global average temperature of about -17 °C, to the climate we have today. Heat-absorbing components contribute directly to that warmth by intercepting and absorbing energy passing through the atmosphere as electromagnetic waves.”*

In describing the “physical science basis” the Intergovernmental Panel on Climate Change (IPCC) in its 2007 “Contribution of Working Group I to the Fourth Assessment Report” (incorrectly, see below) put it this way [8]:

*“The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 Watts per square metre ( $W$*

*m–2). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing longwave radiation. Everything on Earth emits longwave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates. To emit  $240 \text{ W m}^{-2}$ , a surface would have to have a temperature of around  $-19^\circ\text{C}$ . This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about  $14^\circ\text{C}$ ). Instead, the necessary  $-19^\circ\text{C}$  is found at an altitude about 5 km above the surface.*

*The reason the Earth's surface is this warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect."*

The scientists at RealClimate.org also use this  $33^\circ\text{C}$  number in their interpretations [9]:

*"Since we are looking at the whole of the present-day greenhouse effect (around  $33^\circ\text{C}$ ), it is not surprising that the radiative forcings are very large compared to those calculated for the changes in the forcing. The factor of  $\sim 2$  greater importance for water vapour compared to  $\text{CO}_2$  is consistent with the first calculation."*

Virtually all mainstream science and teaching has accepted and parrots this idea that the planetary greenhouse effect on Earth causes a warming of approximately  $33^\circ\text{C}$ . In addition, research scientists use it ( $\langle\epsilon\rangle = 1$ ) in their peer-reviewed published calculations about Earth global processes [1].

But in fact, the evaluation of a 33 degree warming is in serious error. It is not physically reasonable to assume the true value of Earth's average emissivity  $\langle\epsilon\rangle$  to be equal to 1. Indeed, it is physically impossible from usual known radiative processes for any opaque body to have a surface albedo (reflectivity) as high as 0.30 yet have an emissivity of 1. An ideal black body has a reflectivity of zero.

This is not an elusive point in radiation physics. Emissivity has been studied since before the development of quantum mechanics and there exists a first-empirically-established relation between reflectivity (albedo) and emissivity. It is known as Kirchhoff's Law of radiation physics. Basically, it says that the larger the reflectivity the smaller the emissivity, in approximate linear relation to each other.

As an equation, in this context, Kirchhoff's Law is:

$$1 - \langle a \rangle = \langle \epsilon \rangle. \quad (\text{eq.5})$$

It is a violation of Kirchhoff's Law to admit  $\langle a \rangle = 0.30$  yet use  $\langle \epsilon \rangle = 1$  in calculating the Earth's surface temperature, irrespective of the assumed amount of greenhouse effect.

Thus, this fiction which has become an ingrained part of the planetary greenhouse effect scientific folklore is wrong.

Instead, correctly using eq.5 with eq.3 and  $\langle \tau_e \rangle = 1$  gives the much higher Earth surface temperature of  $T_o = 278.6 \text{ K}$  or  $5.5^\circ\text{C}$  for an earth subjected to a complete absence of any planetary greenhouse effects. This was previously emphasized by Hertzberg and Stott in 1994 [10].

Therefore, the total warming from the entire greenhouse effect on Earth is realistically approximately  $8$  to  $9^\circ\text{C}$ , not  $33^\circ\text{C}$ . And even without a greenhouse effect the Earth does not become a solid ball of ice. Kirchoff's Law implies that at relatively constant solar intensity, "ice ages" can only be transient states induced by sudden and large-magnitude changes in planetary properties but they are not stable.

### **Further consequences of Kirchoff's Law**

Recognizing Kirchoff's Law also means that the proportion of long-term habitable planets must be re-evaluated up, for those scientific hobbyist interested in such questions.

Back on Earth, Kirchoff's Law (eq.5) allows one to simplify eq.3 as:

$$T = [ \langle I_s \rangle / \langle \tau_e \rangle \sigma ]^{(1/4)} \quad (\text{eq.6})$$

where, as above, " $^{(1/4)}$ " means "to the power  $1/4$ ". Here, it becomes clear that the dominant long-term steady state parameters determining mean surface temperature are the average solar intensity at Earth (or average solar constant)  $\langle I_s \rangle$  and the net mean longwave atmospheric transmittance  $\langle \tau_e \rangle$ , largely irrespective of surface property changes (i.e., changes in  $\langle \alpha \rangle$  and  $\langle \epsilon \rangle$ ).

In other words, if the reflectance (albedo) is high then the emissivity is low in just such a way as to produce the same global mean surface temperature that produces a global radiation balance. That is, less incoming shortwave solar radiation is absorbed and less outgoing longwave surface emission radiation is produced, for the same mean surface temperature.

### **Evaluating longwave atmospheric transmission, $\langle \tau_e \rangle$**

Given the pivotal role of eq.6 in determining the steady-state mean surface temperature, it becomes important to properly evaluate  $\langle \tau_e \rangle$ . This has not been done correctly in the past, again largely due to a lack of appreciation of Kirchoff's Law. I show below that  $\langle \tau_e \rangle$  has been vastly underestimated. As a result,  $1 - \langle \tau_e \rangle$ , the so-called "longwave radiative forcing" (arising from all greenhouse effects on the planet), has been vastly overestimated.

Arguably the best way to determine  $\langle te \rangle$  using constraints from measured quantities is as follows. Use eq.2 with Kirchoff's Law (eq.5), the measured average surface temperature (14.0°C [3]) and solve for  $\langle te \rangle$ :

$$\langle te \rangle = \langle Is \rangle / \sigma T^4 . \quad (\text{eq.7})$$

This gives  $\langle te \rangle = 0.89$ .

Alternatively (and equivalently),  $\langle te \rangle$  can be calculated from its definition of longwave energy out (escaping the planet) divided by longwave emission energy from the surface. The longwave energy out is measured by satellite to be 239 W/m<sup>2</sup> [1] whereas the longwave emission energy from the surface is calculated from eq.1 with the average emissivity from Kirchoff's Law (eq.5 and measured  $\langle a \rangle$ ) and the measured average surface temperature (14.0°C [3]). Given observed [1] global radiation balance (in = out), the same result is obtained:  $\langle te \rangle = 0.89$ .

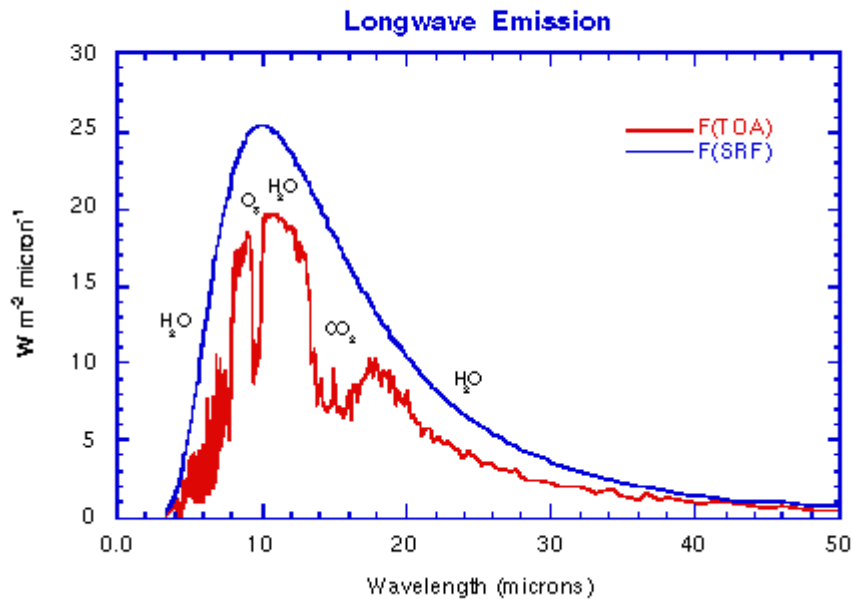
These considerations, to our knowledge, give the first accurate evaluation of  $\langle te \rangle$  for the current Earth:  $\langle te \rangle = 0.89$ . This value is significantly larger than the accepted value in the scientific literature (e.g., [1][11]). The accepted value arises as follows [1][11]: One uses  $\langle \epsilon \rangle = 1$  (as an arbitrary choice and in violation of Kirchoff's Law) and the measured mean surface temperature (14.0°C [3]) with eq.1 to obtain a surface emission intensity of  $\langle I_e \rangle = 396 \text{ W/m}^2$  [1]. By comparison with the satellite-measured outgoing longwave radiation intensity (239 W/m<sup>2</sup> [1]) one has  $\langle te \rangle = 239/396 = 0.60$ , a vastly underestimated value.

The latter incorrect value of  $\langle te \rangle = 0.60$  in turn implies a value of the so-called "longwave radiative forcing" ( $1 - \langle te \rangle$ ) of  $1 - 0.60 = 0.40$  (40%) instead of the correct value of  $1 - 0.89 = 0.11$  (11%).

This means that the accepted magnitude of the longwave radiative forcing for Earth from all greenhouse effects in the atmosphere is an overestimate by a factor of  $\sim 4$  (360%).

Corroboration of our value of  $\langle te \rangle = 0.89$  (rather than 0.60) is contained in the satellite data itself. For example, consider Fig.1 of reference [11] (reproduced below). This figure is for "global cloudy conditions" and shows both the satellite-measured spectrum of longwave radiation escaping to outer space (red curve) and the incorrect assumed model surface emission spectrum (using 14°C and  $\langle \epsilon \rangle = 1$ ) (smooth blue curve). The integrated fractional surface area between the two spectral curves (red and blue) is indeed  $\sim 0.4$  but this is wrong. One sees that the blue curve is artificially uniformly much higher than the correct smooth envelope curve that would match the red curve in the non-scattering parts of the spectrum. The correct envelope curve would result from using  $\langle \epsilon \rangle = 1 - 0.3 = 0.7$  (for global average conditions, cloudy and clear sky) and the corresponding integrated fractional surface area between the red spectral curve and the correct envelope (surface emission) curve would be  $\sim 0.1$ .





The psychological bias from the long-standing “33 degree” error and its underlying assumptions appears to be so strong that even the obvious satellite-measured emission spectra are systematically misinterpreted rather than taken at face value: There is a well defined spectral envelope curve in the measurement (red curve) which is disregarded in favour of an incorrect model curve (bleu curve) that violates Kirchoff’s Law.

Here it is important to note one of several likely reasons that scientists have fooled themselves to this extent. One can measure the longwave scattering transmittance (or cross section) of a greenhouse effect gas (e.g., CO<sub>2</sub>, H<sub>2</sub>O) in the laboratory. However, virtually all such measurements evaluate the loss of transmitted intensity in the incident beam direction, thereby quantifying the amount of longwave radiation (incident on the gas sample) that is not scattered away from the incident beam direction. The error in using this measured total scattering cross section when reasoning with the atmosphere is that much (most) of the scattered (and multiply scattered) radiation will actually escape to outer space and therefore must be counted as part of the atmosphere’s net transmittance <te>.

In other words, one cannot, as has too often been done, calculate atmospheric scattering transmittance from collimated-beam laboratory measurements of scattering cross sections without calculating the escape probabilities for the atmosphere of all the scattered and multiply scattered radiation.

## Refining the model

Having corrected longstanding and pervasive errors in the radiation balance physics for Earth, we now have a robust model (eq.6) that can be used predicatively. Here  $\langle \epsilon \rangle$  directly arises from all contributions from greenhouse effect gases, clouds, etc., and any solar input variations (weather due to solar activity or Earth's orbit) are modelled by  $\langle I_s \rangle$ . In particular, this allows robust sensitivity analyses.

The model (eq.6) can also be further refined by replacing  $\langle I_s \rangle$  with  $[(1 - \langle a \rangle) / \langle \epsilon \rangle] \langle I_s \rangle$  (to reproduce eq.3) in order to consider possible deviations from Kirchoff's Law, where the ratio  $[(1 - \langle a \rangle) / \langle \epsilon \rangle]$  (let us call it the "Kirchoff ratio") would not be exactly equal to 1.

The model could also be refined to include correlations between surface and atmosphere properties in doing the global time (day, season) and planet surface averages, as mentioned above.

The latter two improvements (Kirchoff-deviation and correlations) are expected to produce only small changes in the predictions from the model.

Given the straightforward nature of the model (eq.6) following directly from the most fundamental considerations of radiation physics, those who argue [12][13][14][15] that the more complex circumstances of a real (and thermodynamically active) atmosphere and a real non-uniform and non-smooth surface are such that no net global greenhouse effect warming of the planet surface can result have the burden of the proof in that they must explain in simple physical terms how no warming (whether measurable or not [5][16]) would occur despite the prediction of eq.6.

## Further predictions from the model

Next, let us examine some immediate predictions of the model. In order to facilitate these calculations and also to make them more transparent we express  $\langle \epsilon \rangle$  as 1 minus its deviation from 1. We denote the magnitude of the deviation as  $\delta$  and write:

$$\langle \epsilon \rangle \equiv 1 - \delta \quad (\text{eq.8})$$

Eq.8 defines  $\delta$  and  $\delta = 0.11$  for the present Earth atmosphere.

Since  $\delta$  is small compared to 1, eq.8 allows eq.6 to be written (approximately) as:

$$T = T_o [ 1 + (\delta/4) ] \quad (\text{eq.9})$$

where  $T_o$ , as defined above, is the correct Earth's mean surface temperature in the absence of all greenhouse effects,  $T_o = 278.6$  K.

In this way, any assumed changes in  $\langle \epsilon \rangle$ , due to changes in concentrations of greenhouse effect gases for example, can be modelled as changes in the parameter  $\delta$  which has a linear impact on (mean global) surface temperature  $T$ .

For example, let us use eq.9 to calculate the warming due to the total post-industrial increase in CO<sub>2</sub> atmospheric concentration. In fact, for practical reasons (related to the polynomial expansion approximation used in deriving eq.9 from eq.6), it is more accurate to calculate the cooling that would result from turning the present CO<sub>2</sub> atmospheric concentration (390 ppmv) back to the pre-industrial value (280 ppmv).

The corresponding change  $\Delta\delta$  in the value of  $\delta$  is given by:

$$\Delta\delta = \delta_p F_{CO_2} C_{pre} \quad (\text{eq.10})$$

where  $\delta_p$  is the present value of  $\delta$  arising from all present Earth greenhouse effects,  $F_{CO_2}$  is the present fraction (from 0 to 1) of all greenhouse effects that arise from CO<sub>2</sub>, and  $C_{pre}$  is the fractional change in CO<sub>2</sub> concentration in going from the present value to the pre-industrial value.

As shown above,  $\delta_p = 0.11$ . Also  $C_{pre} = [(280 \text{ ppmv} - 390 \text{ ppmv}) / 390 \text{ ppmv}]$ , corresponding to a 28% decrease. Finally, we need  $F_{CO_2}$ . It can most reliably be obtained from satellite spectral measurements. This was done in [11] but using the incorrect assumed surface emissivity  $\langle \epsilon \rangle = 1$ . This error systematically overestimates the surface emission spectrum, thereby producing a systematically overestimated “longwave radiative forcing” “spectrum”. But since the overestimate is at all wavelengths, we can expect that the fractional contributions for the different greenhouse effect gases, reported by [11], will be approximately correct. Therefore,  $F_{CO_2} \sim 0.26$  (for clear sky conditions).

This gives a net present to pre-industrial change in Earth surface temperature from changing the CO<sub>2</sub> alone while leaving all other parameters constant as:

$$\Delta T_{ind} = T_o \Delta\delta/4 = T_o (\delta_p F_{CO_2} C_{pre})/4 = -0.56 \text{ K} \quad (\text{eq.11})$$

Therefore, the predicted pre-industrial to present warming from the increase in CO<sub>2</sub> alone is approximately 0.56°C.

Similarly, we calculate the effect of doubling the present atmospheric concentration of CO<sub>2</sub> (without changing anything else) using  $\Delta\delta = \delta_p F_{CO_2} C_{x2}$  where  $C_{x2}$  is the fractional change in doubling the CO<sub>2</sub>,  $C_{x2} = [(780 \text{ ppmv} - 390 \text{ ppmv}) / 390 \text{ ppmv}] = 1$ . This gives a predicted warming  $\Delta T_{dbl} = 2.0 \text{ K}$  (or 2.0°C).

And so on. It is immediate to calculate the warming effect of positive or negative so-called water vapour feedback simply by applying the assumed multiplicative factor to the modelled change in CO<sub>2</sub> concentration.

We note that our simple and correct model for global radiation balance gives all the same predictions as the state of the art global circulation models (GCMs). This suggests that the complexities of surface-wise inhomogeneities, altitude-wise atmospheric inhomogeneities, and atmospheric circulation are not relevant to the global mean radiation balance and resulting mean temperatures, as the above simple physics suggests.

One therefore should question the role of these models which are ill-suited to answering questions of global radiation balance. More could be gained from improving satellite data and interpretation and from studying radiation balance parameters on regional scales.

## **Sensitivity analysis of the model**

Finally, let us consider the simple-model-calculated sensitivities regarding mean global surface temperature for different model parameters applied to the present Earth.

Since the solar constant itself varies by 6.7% of its mean value over the course of the seasons, let 6.7% variations be our standard of variation. The results are as follows:

- 6.7% change in  $\langle I_s \rangle$  causes  $\Delta T = 4.7$  K
- 6.7% change in the Kirchoff ratio  $((1 - \langle a \rangle) / \langle \epsilon \rangle)$  causes  $\Delta T = 4.7$  K
- 6.7% change in ALL total greenhouse effects causes  $\Delta T = 0.51$  K

The radiation balance steady state temperature of Earth's surface is an order of magnitude more sensitive to changes in solar constant and Kirchoff ratio than to changes in all sources of planetary greenhouse effects taken together.

It stands to reason, therefore, if reason matters and if we are concerned about the global mean surface temperature, that more research funding should go into studying solar variations and regional/planetary albedo/emissivity relations than trying to deduce the relatively subtle effects of "longwave radiative forcing". After all, large scale human land use changes can have dramatic effects on both surface radiative properties and colloidal atmospheric particle pollution concentrations and depositions.

Likewise, land use practices should be subject to much more scrutiny, if radiation warming is our concern, than CO<sub>2</sub> fluxes into and out of the atmosphere.

I have extensively argued from both the social science and climate science perspectives that global warming should not be our concern regarding environmental destruction and social injustice [5].

## **Relevance to the dominant climate science narrative**

Recently, I critically reviewed the dominant narrative of climate science on several of its central points [17]: That the post-industrial atmospheric CO<sub>2</sub> concentration increase is

directly a result of fossil fuel burning production of CO<sub>2</sub>, that the post-industrial increase in atmospheric CO<sub>2</sub> concentration causes a greenhouse warming, that a measurable global mean surface warming has occurred in the post-industrial period, and that anthropogenic global warming radiative forcing drives “climate chaos” and produces extreme weather events.

The considerations of the present model are not inconsistent with the critical review of reference [17].

The global inter-carbon-pool flux dynamics of exchanges with the atmosphere and the factors affecting these inter-compartment fluxes remain the dominant determinants of the resulting atmospheric CO<sub>2</sub> concentration value [17] (and references therein).

There remains a vehement debate among atmospheric physicists on the question of whether or not a planetary greenhouse effect can occur on a real planet having a greenhouse effect gas bearing atmosphere [12][13][14][15][17]. However, as mentioned above, the simplicity and robustness of the model developed in the present paper imply that scientists claiming a complete absence of a planetary greenhouse effect mechanism should have the onus to provide a simple physical explanation regarding the strict absence of a planetary greenhouse effect in models of the radiation balance with a realistic atmosphere.

The physical-measurement and mathematical-statistics difficulties in obtaining a mean global surface temperature and in estimating the uncertainty error in this mean global surface temperature remain [5][16][17].

The reality of a post-industrial increase in extreme weather events remains undemonstrated and highly contested by climatologists and the physical mechanism whereby “climate chaos” would result from extra-CO<sub>2</sub> “greenhouse radiative forcing” is at the level of a tenuous theoretical fantasy [17].

I hope that the present paper will help to clarify concepts regarding Earth’s planetary radiation balance in relation to global mean surface temperature.

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